

DEVELOPMENT OF COMPLEX, STEREOTYPED BEHAVIOR IN PIGEONS

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A pigeon's peck on one key moved a light down one position in a 5×5 matrix of lights, while a peck on another key moved the light across one position. Reinforcement depended upon the occurrence of four pecks on each key (moving the matrix light from the top left to the bottom right), and a fifth peck on either key ended a trial without food. Though there were 70 different sequences that led to reinforcement, each of 12 pigeons developed a particular, stereotyped sequence which dominated its behavior (Experiment 1). Extinction produced substantial increases in sequence variability (Experiment 2). Removal of the matrix cues disrupted performance, though it partially recovered with extended training (Experiment 3). The pigeons did not master a contingency which required a different sequence on the current trial than on the previous one (Experiment 4), though they were able to learn to emit sequences which began with either left-left or left-right response patterns (Experiment 5). The experiments suggest that contingencies of reinforcement may contribute to the creation of complex units of behavior, and that stereotypy may be a likely consequence of contingent reinforcement.

Key words: response sequences, complex operant, response stereotypy, key peck, pigeons

The goal of most research in the experimental analysis of behavior has been to establish functional relations between a variety of environmental events and the frequency or probability of behavior which is related to those events. Unfortunately, a concentration on the study of functional relations has led to an unnecessary neglect of questions concerning the structure and organization of behavior. Skinner (1935, 1938) has argued that within limits, units of behavior may be created and organized around whatever properties are specified by contingencies of reinforcement; that contingencies influence not only the likelihood of behavior, but also its organization. While it is surely the case that reinforcement contingencies cannot provide a complete account of behavioral organization, their potential importance requires systematic examination.

Shimp (1975, 1976b; see also Staddon, 1974) has argued persuasively that operant work

should focus on the analysis of behavioral structure, and he and others have done some illustrative research along these lines (e.g., Hawkes & Shimp, 1975; Shimp, 1976a, c; see also Grayson & Wasserman, 1979; Straub, Seidenberg, Terrace, & Bever, 1979; Wasserman, 1977). However, the development and organization of operants have not been extensively studied within the operant tradition. There have been studies of various topographical features of individual responses, such as force (e.g., Notterman, 1959), duration (e.g., Notterman & Mintz, 1965; Schwartz 1977a, b; Schwartz & Williams, 1972), and location (Herrnstein, 1961). In each of these studies, however, the basic unit of behavior remained the lever press, or key peck, and the research involved the measurement, and in some cases the manipulation, of some molecular features of the response.

The primary concern of the present research is the extent to which some structure or patterning of complex behavior may be discerned even in situations which do not demand such patterning. An analogy can be made to research on human memory (e.g., Tulving, 1962; 1964; see Shimp, 1976b) which demonstrated that subjects imposed a structure on lists of words to be recalled even when no structure was required or suggested by the

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conditions of the task. Tulving suggested that with repetition of lists of words, complex functional units were constructed out of strings of individual words, with a resultant increase in the recall accuracy of subjects. The question addressed in this research is whether, when pigeons are required to emit a sequence of responses which is relatively unconstrained by the reinforcement contingency, a pattern or structure to that sequence develops with training.

A technique extremely well suited to the study of this question has been reported by Vogel and Annau (1973). Vogel and Annau confronted pigeons with two pecking keys and a 4×4 matrix of lights. At the start of each trial, the top left light in the matrix was illuminated. Pecks on one key moved the light across one position in the matrix; pecks on the other key moved it down one position. When the light reached the bottom right, reinforcement was delivered. Thus, pigeons were required to peck each key three times, in any order. If they pecked either key for a fourth time, the trial ended without reinforcement. This procedure required a sequence of responses, but many possible sequences (20) could satisfy the contingency. Despite this flexibility in the contingency, Vogel and Annau found that each pigeon developed a stereotyped sequence, which occurred on more than 80 percent of the trials.

The Vogel and Annau procedure has several useful features for the study of the development of behavioral units under operant contingencies. First, reinforcement depends on a sequence of responses. Second, in this procedure, the relevant features of the operant are themselves individual key pecks and are thus discrete and easily measured. Third, the Vogel and Annau task permits a wide range of variability without loss of reinforcement. In other words, it is possible for subjects to satisfy the contingency with sequences of responses which differ from trial to trial; that is, the task does not demand the development of a single, integrated sequence. As a result, it is possible to assess the extent to which reinforcement contingencies produce integrated sequences even when they are not required. The present series of experiments lays some of the groundwork for the analysis of the structure of complex operants by demonstrating that contingent reinforcement produces

stereotyped, complex response sequences and by exploring some possible influences on the degree of stereotypy observed.

GENERAL METHOD

Subjects

Twelve experimentally naive White Carneaux pigeons were maintained at 80% of free feeding weight.

Apparatus

A Gerbrands pigeon chamber (G7313) contained a three-key pigeon intelligence panel. The keys were Gerbrands normally closed keys, requiring a force of at least .1 N to operate. They were spaced 7.5 cm apart, center to center, and were located 21 cm above the grid floor. A grain hopper was located directly below the center key, 5.5 cm above the grid floor, and a pair of houselights was located in the ceiling of the chamber. The houselights were illuminated throughout experimental sessions except during 4-sec feeder operations, when a light in the feeder was illuminated.

A 5×5 matrix of red lights was mounted on the left sidewall of the chamber. The lights were .84 cm in diameter, and .04 amp (Dialco No. 507-3917-1471-60D). The lights in the matrix were spaced 2 cm apart. The top row of lights was 20 cm from the grid floor, and the right-most column (closest to the intelligence panel) was 4 cm from the panel.

Scheduling of experimental events, data collection, and data analysis were accomplished with a Digital Equipment Corporation PDP 8/E digital computer using interfacing and software provided by State Systems Incorporated, Kalamazoo, Michigan.

General Procedure

Pretraining. The pigeons were trained to eat from the food magazine, after which they were exposed to a modified autoshaping procedure (Brown & Jenkins, 1968). Each session consisted of 50, 6-sec trials, separated by a variable intertrial interval (mean = 40 sec). Each of three trial types was equiprobable: either the left key was illuminated with white light, or the right key was illuminated with white light, or both keys were. These three types of trials occurred in random order. After

6 sec, the keylight(s) was extinguished and the feeder operated. Key pecks were recorded but had no programmed consequence. Each pigeon was exposed to the autoshaping procedure for five full sessions after the one in which pecking began. At the end of pretraining, all pigeons were reliably pecking both keys (when illuminated).

General Sequence Training Procedure. Daily sessions consisted of 50 trials separated by an intertrial interval of 10 sec. At the beginning of each trial, the two side keys were illuminated with white light and the top left matrix light was lit. Each peck on the left key extinguished the currently illuminated matrix light and lit the one to its right; each peck on the right key also extinguished the currently illuminated matrix light and lit the one beneath it. Four left-key pecks were required to move the matrix light from extreme left to extreme right, and four right-key pecks were required to move the matrix light from extreme top to extreme bottom. In all the experiments reported below, to obtain reinforcement it was necessary (though not always sufficient) to move the matrix light from the top left to the bottom right. In short, it was necessary to peck each key four times. A fifth peck on either key terminated a trial without reinforcement. In all, there were 70 different sequences of left- and right-key pecks which could satisfy the reinforcement contingency.

EXPERIMENT 1 DEVELOPMENT OF A COMPLEX OPERANT

Vogel and Annau (1973) demonstrated that when pigeons were exposed to a task in which reinforcement was available for each of 20 possible response sequences including three pecks on each of two keys, one particular sequence came to dominate the behavior of each pigeon. The present experiment was designed to replicate the Vogel and Annau result. The main procedural difference between this experiment and the Vogel and Annau experiment was that four responses were required on each key rather than three.

SUBJECTS AND PROCEDURE

The twelve experimentally naive White Carneaux pigeons were exposed first to the pretraining procedure and then to the general

training procedure described above. They were exposed to this sequence procedure for 40 daily sessions. Pigeons 9 through 12 were included several months after data had been collected for Pigeons 1 through 8.

RESULTS AND DISCUSSION

The data of main interest in this and subsequent experiments are as follows: (a) the number of successful (reinforced) sequences emitted; (b) the number of different sequences emitted; and (c) the frequency of occurrence of the sequence which became dominant in the behavior of each pigeon. Figure 1 presents the number of different sequences emitted and the number of reinforcers obtained for each pigeon, across Sessions 1 through 5 and Sessions 36 through 40 of the sequence procedure. In the first 5 sessions, pigeons obtained between 25 and 90 of 250 possible reinforcers (mean = 51.2). In the last 5 sessions, they obtained between 120 and 220 reinforcers (mean = 169.0). In the first 5 sessions, they emitted between 55 and 172 different sequences (mean = 110.4). By the last 5 sessions, the number of different sequences was reduced to between 12 and 65 (mean = 29.0). This increase in success and decrease in variability occurred gradually over 25 to 30 sessions for most of the pigeons. By the end of the training, there was little session-to-session variability in the data of individual pigeons. Standard deviations in reinforcements per session ranged from .7 to 3.2, and standard deviations in number of different sequences ranged from .6 to 1.8.

Figure 2 presents the frequency of the sequence which became dominant for each of the pigeons, across Sessions 1 through 5 and 36 through 40. The figure also indicates, for each pigeon, what that sequence was. In Sessions 1 through 5, the frequency of the dominant sequence ranged from 2 to 75 (mean = 16.8). Pigeon 6 was the only one for which the dominant sequence at the end of training was also the dominant one at the beginning of training. By the end of training, the frequency of the dominant sequence ranged from 78 to 220 (mean = 145.8). For 9 of the 12 pigeons, the dominant sequence which emerged was the simplest, requiring only one switch between keys. The dominant sequence for the other three (P7, P9, and P10) involved more switching and occurred at a lower frequency

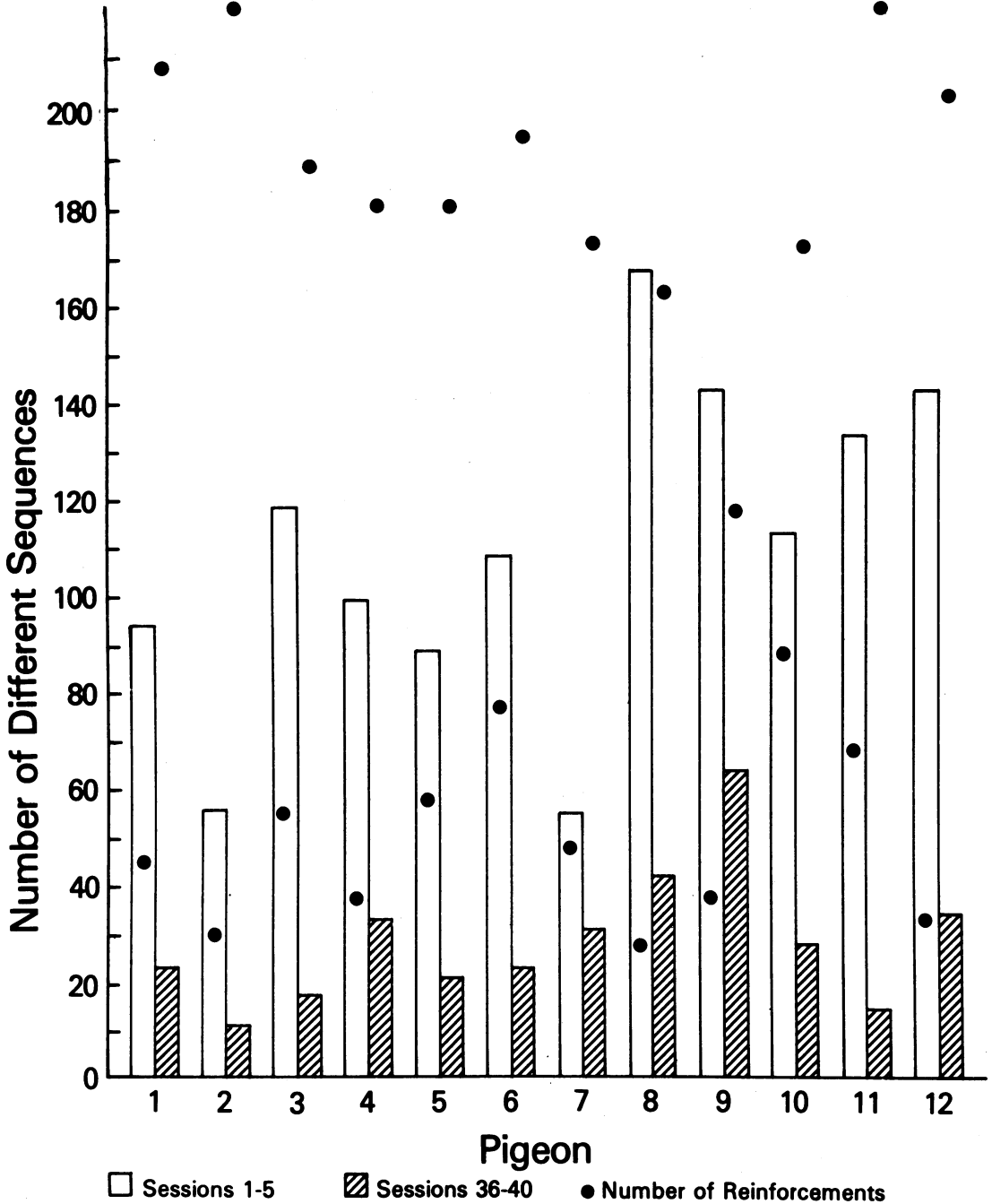


Fig. 1. Number of different sequences emitted by each pigeon in the first five (open bars) and last five (striped bars) sessions of the sequence procedure. Points inside or above each bar indicate the number of reinforcements obtained in those sessions.

than the dominant sequences of all of the other pigeons but P4. By the end of training, the behavior of each pigeon was quite stable, with standard deviations across the last five

sessions ranging from 1.1 to 3.0.

In the terminal performances of the pigeons whose behavior was most stereotyped (Pigeons 1, 2, 3, 6, 11, and 12), most unsuccessful se-

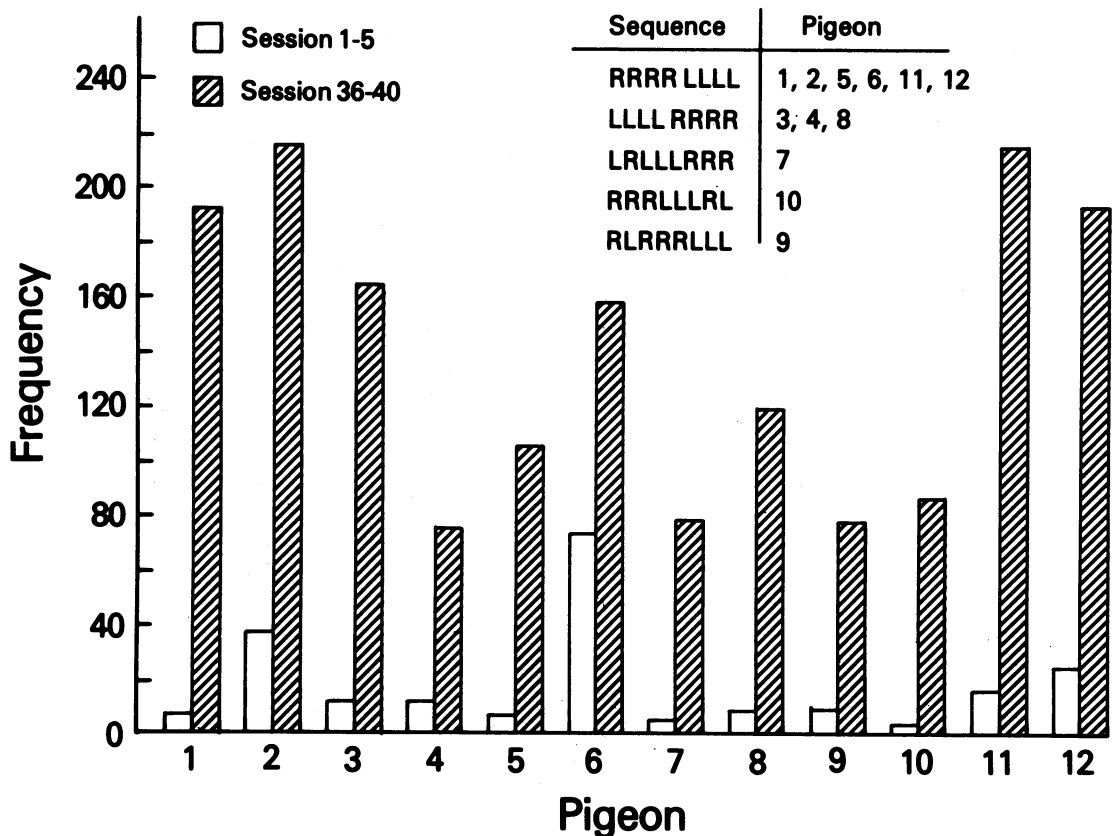


Fig. 2. Frequency of the sequence which became dominant for each pigeon in the first five (open bars) and last five (striped bars) sessions of the sequence procedure. The dominant sequence for each pigeon is indicated in the top right corner of the figure.

quences were errors of perseveration or anticipation. Thus, Pigeon 11, which emitted the sequences RRRRLLLL in 220 of 250 trials, emitted the sequence RRRRR in 16 trials, and RRRLLLLL in 9 trials. The errors of the pigeons whose behavior was least stereotyped were more variable and less obviously related to the dominant sequence. However, even the behaviors of these pigeons were stereotyped with respect to the beginning of a sequence. On average, 241 of 250 trials began with a peck to the same key.

The present findings replicate those of Vogel and Annau (1973) in a situation which permitted even more variability of response sequencing than theirs. With no explicit contingency imposed on response sequencing, a dominant sequence emerged for each pigeon. Satisfaction of the contingency requiring four pecks on each key and emergence of a stereo-

typed or preferred sequence co-occurred. The pigeons with the most stereotyped behavior were also those with the greatest proportion of reinforced sequences. Across the 12 pigeons, a mean of 145.8 out of 169.0 reinforcers were obtained by engaging in the dominant sequence.

It is difficult to assess the extent to which the behavior of the pigeons was controlled by the contingency requirement. Such an assessment requires a model of how pigeons would allocate their pecks on the two keys in the absence of control by the contingency. If one assumes that each time the pigeon pecks, it is equally likely to peck the left or right key, independent of the location of its last peck, then the pigeons will obtain an average of about 19 reinforcers per session. All the pigeons except Pigeon 9 averaged upwards of 33 reinforcers per session.

EXPERIMENT 2 EFFECTS OF EXTINCTION ON SEQUENCE STEREOTYPY

There are a number of demonstrations that when conditioned responses are extinguished, the topography of the response increases in variability (e.g., Antonitis, 1951; Guthrie & Horton, 1946; Notterman, 1959; Warden & Lubow, 1942). In each of these cases, properties of individual responses were of main interest. The present experiment was concerned with whether extinction increases the variability of response sequences. Thus, pigeons which were well trained on the sequence task were exposed to an extinction procedure, then reexposed to the sequence procedure.

SUBJECTS AND PROCEDURE

The 12 pigeons from Experiment 1 served as subjects. For Pigeons 1 through 8, 60 sessions on other sequence procedures, including 40 in which reinforcement for appropriate sequences was probabilistic, intervened between Experiments 1 and 2.

The present experiment had three phases: first, all pigeons were exposed to the sequence procedure for 20 sessions; next, extinction was introduced for five sessions; finally, the sequence procedure was reintroduced for five sessions. The extinction procedure was identical in every way to the sequence procedure except that food deliveries were omitted.

RESULTS AND DISCUSSION

The relevant data for all pigeons are presented in Figure 3 which shows the number of different sequences and the frequency of the dominant sequences for each pigeon for the last five sessions of the sequence procedure, the five sessions of extinction, and the five sessions of the sequence procedure which followed extinction. The data for all pigeons were similar: in extinction, sequence variability increased dramatically, as measured by both the variety of sequences which occurred and the frequency of the dominant sequence. For example, the mean number of different sequences for the 12 pigeons on the 20th sequence session was 7.3; in the fifth extinction session, it was 31.2. Similarly, the mean frequency of the dominant sequence was 31.1 in Session 20 of the sequence procedure, and 9.4 in Session 5 of the extinction procedure. When

the sequence procedure was reintroduced, sequence stereotypy quickly recovered to pre-extinction levels in all pigeons.

For 8 of the 12 pigeons, the dominant sequence that emerged after extinction was the same one that had been dominant before extinction (see Figure 2). However, for Pigeons 3, 5, 6, and 7, the dominant sequence changed. For Pigeon 3, it became LRLRLRRR; for Pigeon 5, it became LRLRLRLR; and for Pigeons 6 and 7, it became LLLRLRRR. One striking finding is that despite the change in dominant sequence for these pigeons, substantial stereotypy developed just as rapidly as it did for the other pigeons. Moreover, none of these newly dominant sequences occurred with appreciable frequency (more than five times in a session) during the extinction procedure itself.

The increase in sequence variability during extinction was made up largely of sequences which satisfied the contingency requiring four pecks on each key. Averaging across the 12 pigeons and the 5 sessions of extinction, 62.4% of all sequences satisfied the contingency. For individual pigeons, the range was from 38% (Pigeon 9) to 86% (Pigeon 12). Many of the sequences which failed to include four pecks on each key were made up of five consecutive pecks on one of the keys and none on the other.

Finally, the extinction procedure had obvious effects on response rate. For Pigeons 1 through 8, which had previously been exposed to partial reinforcement, the decrease in response rate was gradual. Mean time per trial reached 28.5 sec, averaged across the eight pigeons, by the fifth extinction session. However, in the first extinction session, mean time per trial was 10.0 sec, only 1.4 sec longer than it had been on partial reinforcement. For Pigeons 9 through 12, the effects of the extinction procedure on response rate were larger and more abrupt. Mean time per trial was 17.8 sec in the first session and 45.6 sec in the fifth. Unsystematic observation of all pigeons suggested that the extra trial time was primarily taken before the first peck; there were few instances observed of prolonged pausing during a trial once responding had begun. Aside from changes in response rate, Pigeons 1 through 8 did not seem to differ from Pigeons 9 through 12 in sensitivity to the extinction procedure. Thus, the present

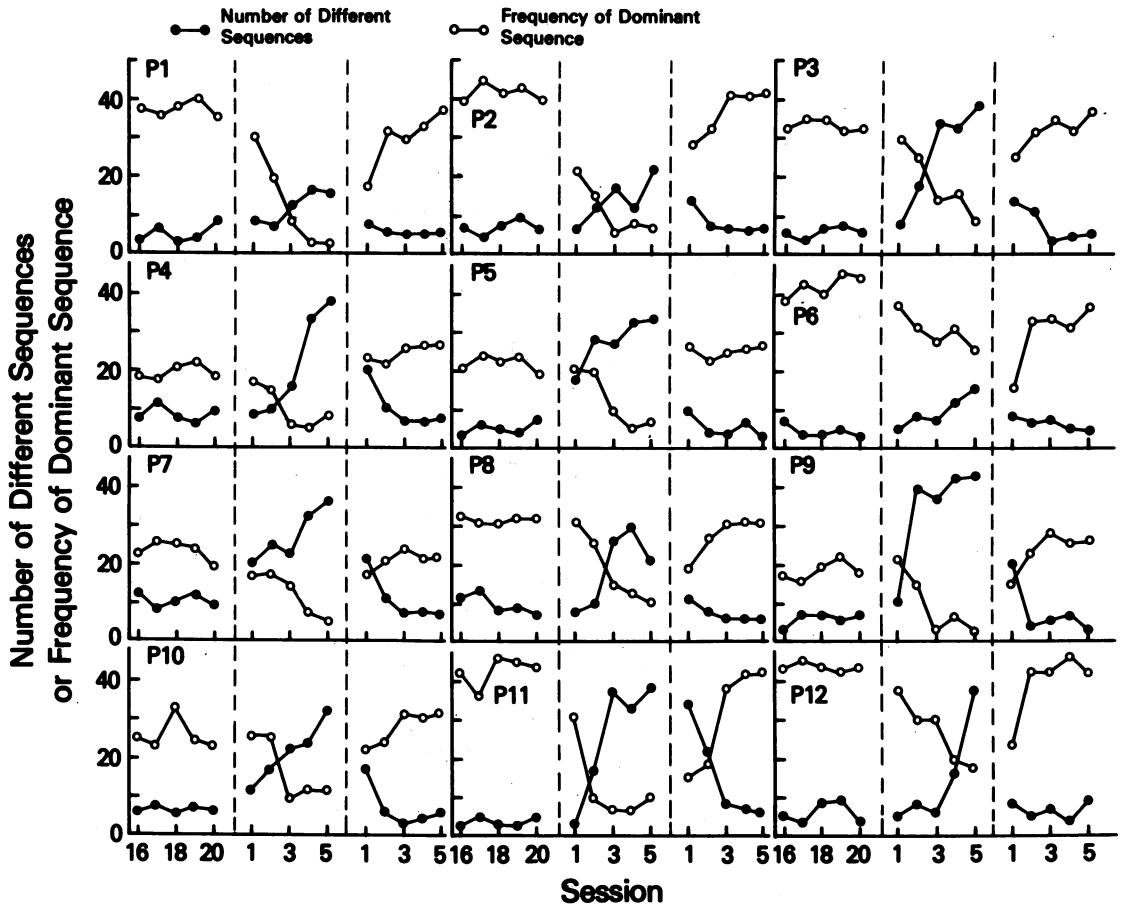


Fig. 3. Number of different sequences (filled circles) and frequency of the dominant sequence (open circles) for each pigeon, in each of the last five sessions of the sequence procedure which preceded the extinction procedure (first panel), in each of the five extinction sessions (second panel), and in the first five sessions of the sequence procedure which followed extinction.

experiment demonstrates that an extinction procedure increases the variability of response sequencing. This finding is consistent with past research and with conventional wisdom about what effects extinction procedures should have.

EXPERIMENT 3 ROLE OF THE LIGHT MATRIX IN CONTROLLING RESPONSE SEQUENCES

In Vogel and Annau's (1973) experiment, two well-trained pigeons were exposed to the sequence procedure without the light matrix. Eliminating the matrix cues resulted in a precipitous decrease in the number of successful sequences, indicating that the matrix lights had been controlling pecking. However, per-

formance without the matrix cues quickly began to improve and was still improving when the procedure was terminated. The present experiment was an attempt to replicate the Vogel and Annau finding, with exposure to the sequence procedure without matrix cues prolonged to assess whether recovery might be complete.

SUBJECTS AND PROCEDURE

Immediately after Experiment 2, the 12 pigeons were exposed to 20 sessions of the sequence procedure, after which they were exposed to an additional 40 sessions with all matrix cues absent.

RESULTS AND DISCUSSION

Figure 4 presents data for each pigeon from the last four sessions of the sequence proce-

ture with matrix cues and from the first and last four sessions without the matrix cues. For each of these blocks of sessions (indicated on the x-axis), the total number of reinforcements obtained, the total number of different sequences emitted, and the frequency of the dominant sequence are presented. In addition, the dominant sequence of each pigeon is indicated. Eliminating the matrix cues resulted in decreases in reinforcement frequency and increases in sequence variability for all pigeons but Pigeon 6. The magnitude of these effects varied greatly. In comparisons between the last four sessions with matrix cues present and the first four with the cues absent, the mean decreases in reinforcements obtained was 58.7 (range = 3-125). The mean increase in the number of different sequences was 67.4 (range = 26-106). Finally, the mean decrease in the frequency of the dominant sequence was 66.7 (range = 5-130). Over the course of

40 sessions without the matrix lights, reinforcement frequency increased and response variability decreased for all but Pigeons 4 and 5. Again, however, there was great variability. For Pigeons 7 and 11, there was almost complete recovery. For all the other pigeons, recovery was incomplete. There was substantial within-subject variability in performance in the early sessions without the matrix cues, but by the end of training, standard deviations were similar to those obtained in Experiment 2.

Whether the observed performances in the absence of matrix cues represent maximal efficiency and stereotypy under such conditions is difficult to determine. It is possible that further exposure to the sequence procedure without matrix cues would have produced still more recovery, though there was no sign in the behavior of any pigeon that performance was still improving by Session 40. Perhaps

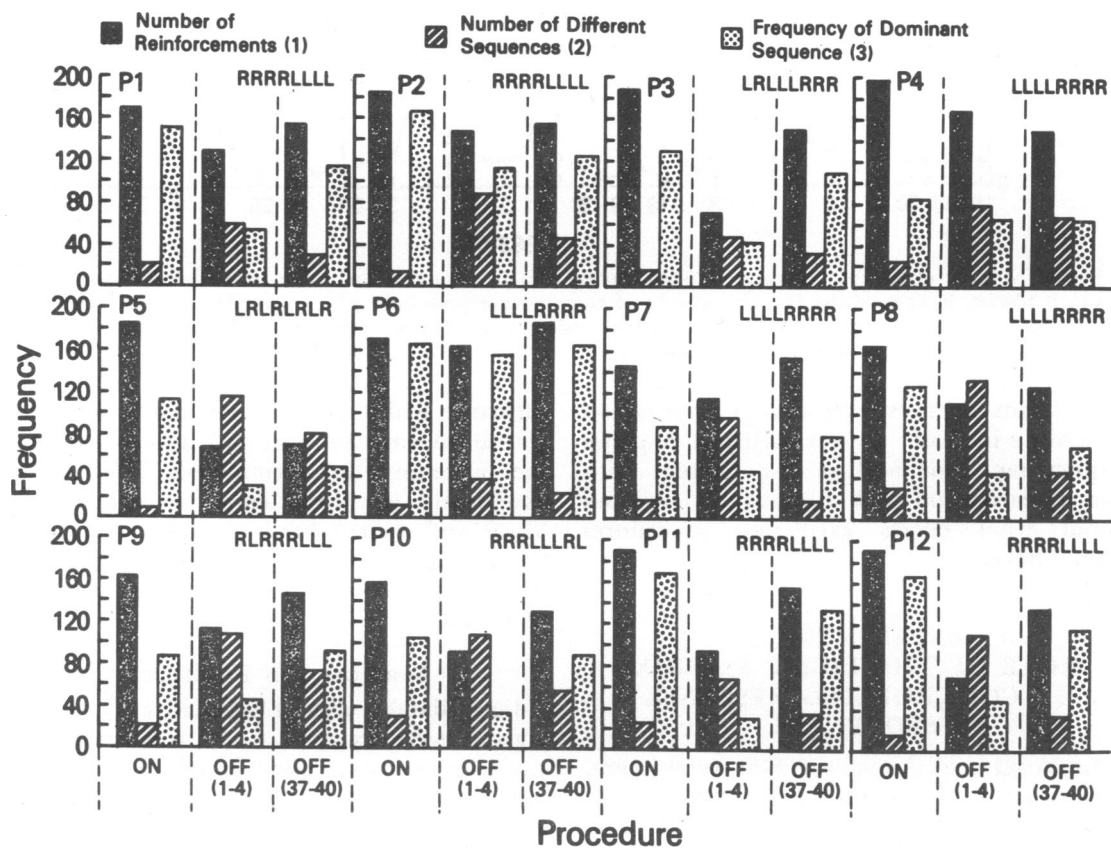


Fig. 4. Number of reinforcements (filled bars), number of different sequences (striped bars), and frequency of the dominant sequence (stippled bars) are presented for each pigeon, for the last four sessions of the sequence procedure with the matrix lights on, and for the first and last four sessions with the matrix lights off. The dominant sequence of each pigeon is also indicated.

more likely is the possibility that pigeons trained from the outset without matrix cues would reach higher levels of efficiency and stereotypy than any of these matrix-experienced pigeons. This possibility remains to be explored in further research.

EXPERIMENT 4 AN ATTEMPT TO TRAIN SEQUENCE VARIABILITY

The preceding experiments have provided evidence that, even when pigeons can obtain reinforcement for any one of a variety of different complex response patterns, a dominant, stereotyped response pattern develops. Since, for most pigeons, the dominant sequence which developed was the most efficient one (either LLLRRRR or RRRLLLL) in that it minimized switching between keys, one could argue that stereotypy was the result of differential reinforcement of the most efficient sequence. That is, one could argue that all 70 possible successful sequences were not equivalent, that 2 of the 70 were selected by the contingency. One could argue similarly that the efficient, stereotyped lever press or key peck which emerges in the rat or pigeon is also the result of differential reinforcement of the least effortful, most rapid form of response. While it is true that not all of the pigeons in these experiments developed maximally efficient sequences, and that the behavior of those which did not (Pigeons 7, 9, and 10 in Experiment 1; Pigeons 3, 5, 9, and 10 in Experiment 3) were nevertheless stereotyped, it is also the case that a rat will occasionally develop an inefficient but stereotyped lever press. On such occasions, one might properly argue that the contingency on maximal efficiency simply was not powerful enough to influence the animal's behavior.

From the argument that stereotypy results from a contingency which selects the most efficient sequence, one might expect that in a sequence task in which all sequences were in fact equally efficient, stereotypy would not develop. It is difficult to design such a task because it is always possible to find post hoc differences in efficiency. Thus, the present experiment attempted to assess whether stereotypy is the result of differential reinforcement in a different way. Pigeons were exposed to the sequence procedure with the typical re-

quirement that four pecks be made on each key. However, an additional requirement was also imposed: to produce reinforcement, a sequence had to be different from the sequence which had occurred on the immediately previous trial. Thus, the higher the frequency of the pigeon's dominant sequence was, the lower the frequency of reinforcement would be. Efficient performance on this task would require a decrease in the frequency of a pigeon's dominant sequence.

SUBJECT AND PROCEDURE

Pigeons 1 through 8 were exposed to five sessions of the sequence procedure immediately after Experiment 3. Then, an additional contingency was added, which required that a sequence on trial $N+1$ be different from the sequence which had occurred on trial N . The pigeons were exposed to 40 daily sessions of this procedure.

RESULTS AND DISCUSSION

Figure 5 presents the number of different sequences which occurred and the number of reinforcements obtained over the first five

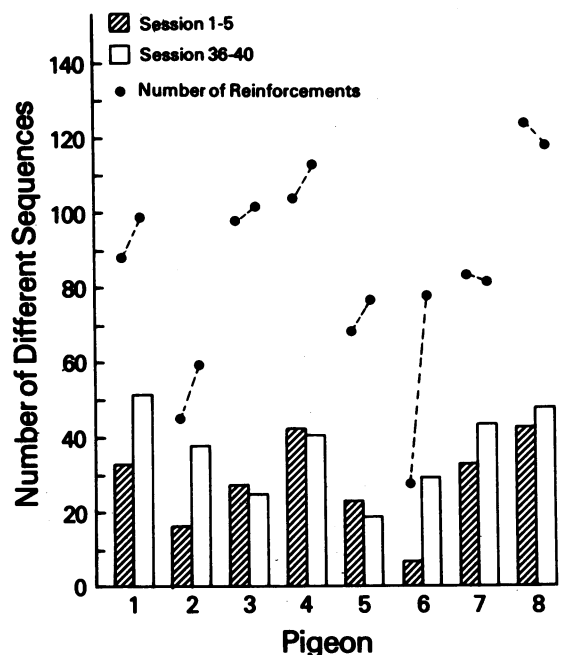


Fig. 5. Number of different sequences and number of reinforcements obtained by each pigeon across the first and last five sessions of the sequence procedure in which sequences were only reinforced if they differed from the preceding sequence.

and the last five sessions of the procedure. With the possible exception of Pigeon 6, it is clear that the pigeons did not master the variability contingency. The mean number of reinforcements obtained in the first sessions was 79.0; in the last five, it was 90.0. The difference is not significant [$t(14) = 0.86$]. If the data for Pigeon 6 are excluded, the means are 86.8 and 91.4. Sequence variability increased marginally, with the mean number of different sequences changing from 27.6 (Sessions 1 through 5) to 34.8 (Sessions 36 through 40). Again, the difference is not significant [$t(14) = 1.76$]. There was little within-subject variability by the end of training. The largest standard deviation in reinforcement obtained was 2.8; in number of different sequences it was 2.1. A similar picture emerges from consideration of the frequency of the dominant sequence. These data, for the first and last five sessions of the procedure, are presented in Figure 6. The mean frequency of the dominant sequence for Sessions 1 through 5 was 131.0, and for Sessions 36 through 40 it was 107.8 [$t(14) = 0.80$]. The behavior of Pigeon 6 was the main contributor to this decrease; with Pigeon 6 excluded, the means were 118.6 and 105.7.

Thus, the present procedure was relatively ineffective in producing more than minor alterations in the stereotyped response patterns

of these pigeons. And substantial variability was not even required to satisfy the contingency. A pattern of strict alternation between two sequences would have been sufficient to produce reinforcement on every trial. (We had intended to require more variability by extending the contingency backward over more trials, e.g., the sequences on trial N would have had to differ from the last *two* sequences; however, the results of this experiment made such further manipulations seem unnecessary.)

There are a number of different interpretations of these data available. One is that contingent reinforcement cannot effectively train variability, at least in pigeons. There is some evidence that variability can be trained in porpoises (Pryor, Haag, & O'Reilly, 1969), though their data could be viewed as largely reflecting a series of conditioning and extinction curves, with extinction occurring more rapidly on each successive occasion. There is also some evidence that variability can be trained in nursery school children (Goetz & Baer, 1973), although in that study, as the authors point out, the contingent reinforcement may have been effective because it provided informative feedback and not because it strengthened variable behavior. There is substantial evidence that variability occurs without training in rats, at least in spatial learning situations (e.g., Dashiell, 1930; Olton, 1979, Olton & Samuelson, 1976). The clearest evidence that variability can be trained comes from a study by Blough (1966) in which inter-response time variability was produced by a schedule in which only infrequent inter-response times were reinforced. The variability in this study was in the distribution of responses in time, not in response form. There does not appear to be any unambiguous evidence that reinforcement can increase variability of response form.

A second possibility is that the task is too difficult for pigeons, not because it requires variability, but because it requires that they remember their last sequence. In fact, the task does not really require that pigeons remember whole sequences. It would be sufficient to remember where the last sequence began. Indeed, the pigeons could do rather well by remembering where the last sequence had ended. Though there is some evidence that delays of only a few seconds impair choice behavior of pigeons which depends on pre-

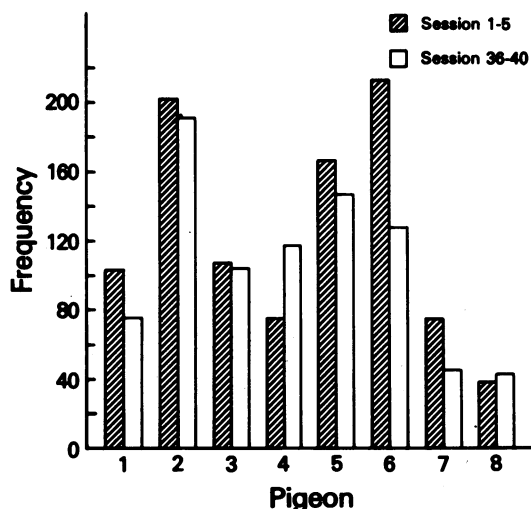


Fig. 6. Frequency of the dominant sequence for each pigeon across the first and last five sessions of the sequence procedure in which sequences were only reinforced if they differed from the preceding sequence. For dominant sequence of each pigeon, see Figure 4.

vious choices (Shimp, 1976c), there is also recent evidence of pigeons' ability to remember previous responses (e.g., Grayson & Wasserman, 1979; Straub, Seidenberg, Terrace & Bever, 1979). Thus, the contribution of memory limitations to the present results requires further investigation.

A third possible interpretation is that the present subjects were simply too well trained for the contingency to be effective, that stereotyped sequences had become sufficiently dominant and "unitized" so that they were extremely resistant to change. One way to evaluate this possibility is to expose naive pigeons to the variability contingency with the expectation that, before a dominant sequence has developed, variability will be more easily trainable. This will be the subject of future research. A second way to evaluate this possibility is to require these same well-trained pigeons to emit sequences which differ from their dominant ones. A demonstration that they could learn such sequences would undermine the claim that extended exposure to the sequence procedure had made their sequences inflexible. Such an evaluation was the objective of Experiment 5. Whether any of these interpretations of the present experiment proves persuasive or some other interpretation develops, the present data suggest that it is not simply differential reinforcement of efficiency which is responsible for the stereotypy observed on the matrix task.

EXPERIMENT 5 TRAINING SEQUENCES WITH INTERNAL CONSTRAINTS

As indicated in the discussion of Experiment 4, the failure of pigeons to learn to vary sequences from trial to trial could have been the result of extended exposure to the sequence task, which had made their particular dominant sequences inflexible. It could also have been the result of task complexity: it may be that pigeons cannot effectively meet any constraint imposed upon the sequences they emit. The present experiment was designed to evaluate both of these possibilities, by exposing the experienced pigeons to a sequence task which (a) required a change in their dominant sequence and (b) imposed an internal constraint on sequences but did not require variability.

SUBJECTS AND PROCEDURE

The eight subjects from Experiment 4 were exposed to a variant of the sequence procedure which imposed a constraint on the first two responses of the sequence. For Pigeons 1, 2, 3, and 5, only sequences which began with two left key pecks were reinforced. For Pigeons 4, 6, 7, and 8, only sequences which began with a left-right alternation were reinforced. In addition, all successful sequences had to satisfy the general contingency which required four pecks on each key. After 40 sessions, the assignment of pigeons to conditions was reversed for 40 sessions; Pigeons 1, 2, 3, and 5 had to begin sequences with an LR combination, and the others had to begin with an LL combination. In the case of each pigeon, the new contingency required a modification of the dominant sequence. The dominant sequence for Pigeons 1 and 2 had begun RR; for Pigeons 3 and 5, it had begun LR. Now, for these four, LL beginnings were required. Pigeons 4, 6, 7, and 8 were required to switch from dominant sequences beginning LL to sequences beginning LR.

RESULTS AND DISCUSSION

Figure 7 presents the number of reinforcements per session for each pigeon on each procedure. The filled circles are from the procedure requiring sequences which began LL, and the open circles are from the procedure requiring sequences which began LR. All 8 pigeons learned to modify their sequences to satisfy the contingencies, reaching an asymptote of 30 to 35 reinforcers per session (out of 50 trials) in almost every case. Acquisition was generally slow, with five or more sessions required before any improvement in performance was noted. Once improvement began, however, it was generally rapid, with asymptotic performance reached by the 20th session. The most striking example of this pattern was the behavior of Pigeon 8 on the LR procedure. For 15 sessions, there was no improvement in obtained reinforcements. Once improvement began, it was complete within seven sessions. The clearest exceptions to this pattern were in the performance of Pigeons 1, 2, and 7 on the LR procedure and of Pigeon 8 on the LL procedure. The sequences of Pigeons 1 and 2 came to meet the LR requirement very slowly and never reached the levels which were

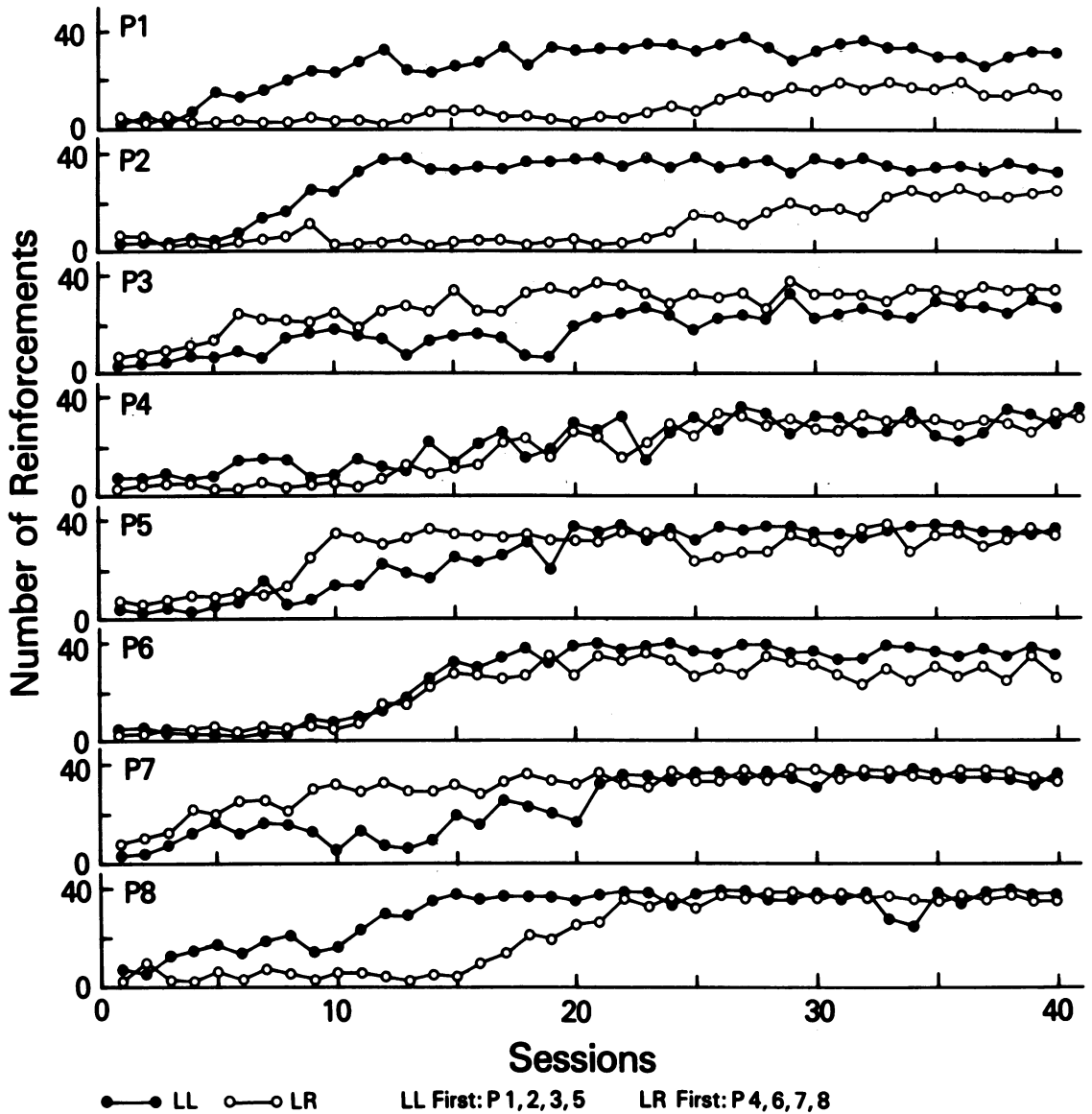


Fig. 7. Number of reinforcements per session (out of 50 possible reinforcements) for each pigeon plotted separately for the sequence procedure requiring sequences beginning with two left key responses (filled circles) and the sequence procedure requiring sequences which began with left-right alternation (open circles). The bottom of the figure indicates which pigeons began with the left-left requirement and which began with the left-right requirement.

reached by the other pigeons and by these pigeons on the LL procedure. In contrast, Pigeon 7 (on LR) and Pigeon 8 (on LL) began to show improvement almost immediately. Except for Pigeons 1 and 2, there were no differences as a function of what procedure came first. There were also no systematic differences in rate of acquisition as a function

of either contingency requirement or the order of procedure.

Table 1 presents, for each pigeon, the sequence which became dominant and its frequency over the last five sessions of LL and LR procedures. Inasmuch as the frequencies of these sequences were negligible in every case at the start of the relevant procedure,

Table 1

Frequency of the dominant sequence over the last five sessions of LL and LR procedures for each pigeon.

Pigeon	Procedure			
	Sequence	Frequency	Sequence	Frequency
1	LLLLRRRR	143	LRLLLLRRR	70
2	LLLLRRRR	124	LRRLRLRLR	92
3	LLRRRRLL	118	LRRRRLLL	162
4	LLLLRRRR	147	LRLLLLRRR	142
5	LLRRLLRR	168	LRRLRLRLR	151
6	LLLLRRRR	141	LRRLLLLRL	101
7	LLLLRRRR	163	LRRRRLLL	163
8	LLLLRRRR	176	LRLLLLRRR	167

these data are not shown. Six of eight pigeons developed dominant sequences of LLLLRRRR on the LL procedure. Averaged across the pigeons, the dominant sequences comprised 92% of all sequences which were reinforced. On the LR procedure, the dominant sequence was more variable, and its frequency somewhat lower than on the LL procedure. Averaged across the pigeons, the dominant sequences comprised 91% of all sequences which were reinforced. Within-subject variability was quite small, as in the other experiments reported. Standard deviations in frequency of the dominant sequence did not exceed 3.1 at the end of training with either the LL or the LR requirement.

The present data indicate that it is possible for pigeons to learn contingencies which impose internal constraints on sequences in the matrix task, and that it is possible for even well-trained pigeons to modify their dominant sequence, at least under some circumstances. These data suggest that the failure of pigeons to learn to vary sequences in Experiment 4 requires a different explanation.

GENERAL DISCUSSION

The present series of experiments has replicated and extended the findings of Vogel and Annau (1973). When pigeons were required to make four pecks on each of two keys to produce reinforcement, one particular sequence (of 70 possible successful sequences) came to dominate their behavior. Extinction significantly increased sequence variability. Attempts to train pigeons to emit different sequences from trial to trial failed, though they were able to learn to begin sequences with particular two-response patterns (left-left or

left-right). Efficient performance was substantially controlled by the matrix of lights, the illumination of which changed systematically as the pigeon worked through the sequence.

The present experiments indicate that reinforcement of a complex sequence of responses produces stereotypy even when stereotypy is not a requirement of the task. The present findings invite the inference that for each pigeon, the dominant sequence has become a unit of behavior with integrity and internal structure. This inference requires empirical support, and further research should be directed toward evaluating the extent to which sequences have become "unitized" and at uncovering their internal structure. Attempts along these lines might include treating sequences as operants and reinforcing them on schedules, disrupting sequences by imposing delays at various points in their execution, and training pigeons to discriminate among different required sequences and assessing the difficulty of discrimination as a function of characteristics of the sequences to be discriminated. To the degree that these studies suggest that sequences may be appropriately viewed as complex behavioral units, they will provide support for the view implicit in the operant framework that units of behavior are created by operant contingencies (Shimp, 1976b).

REFERENCES

- Antonitis, J. J. Response variability in the white rat during conditioning, extinction, and reconditioning. *Journal of Experimental Psychology*, 1951, **42**, 273-281.
- Blough, D. S. The reinforcement of least-frequent interresponse times. *Journal of the Experimental Analysis of Behavior*, 1966, **9**, 581-591.
- Brown, P., & Jenkins, M. Auto-shaping of the pigeon's key-peck. *Journal of the Experimental Analysis of Behavior*, 1968, **11**, 1-8.
- Dashiell, J. F. Direction orientation in maze running by the white rat. *Comparative Psychology Monographs*, 1930, **7**, 72.
- Goetz, E. M., & Baer, D. M. Social control of form diversity and the emergence of new forms in children's blockbuilding. *Journal of Applied Behavior Analysis*, 1973, **6**, 209-217.
- Grayson, R. J., & Wasserman, E. A. Conditioning of two-response patterns of key pecking in pigeons. *Journal of the Experimental Analysis of Behavior*, 1979, **31**, 23-29.
- Guthrie, E. R., & Horton, G. P. *Cats in a puzzle box*. New York: Holt, Rinehart, 1946.
- Hawkes, L., & Shimp, C. P. Reinforcement of behav-

- ioral patterns: Shaping a scallop. *Journal of the Experimental Analysis of Behavior*, 1975, 23, 3-16.
- Herrnstein, R. J. Stereotypy and intermittent reinforcement. *Science*, 1961, 133, 2067-2069.
- Notterman, J. M. Force emission during bar pressing. *Journal of Experimental Psychology*, 1959, 58, 341-347.
- Notterman, J. M., & Mintz, D. E. *Dynamics of response*. New York: Wiley, 1965.
- Olton, D. Mazes, maps and memory. *American Psychologist*, 1979, 34, 583-596.
- Olton, D., & Samuelson, R. J. Remembrance of places passed: Spatial memory in rats. *Journal of Experimental Psychology: Animal Behavior Processes*, 1976, 2, 97-116.
- Pryor, K. W., Haag, R., & O'Reilly, J. The creative porpoise: Training for novel behavior. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 653-661.
- Schwartz, B. Studies of operant and reflexive key pecks in the pigeon. *Journal of the Experimental Analysis of Behavior*, 1977, 27, 301-313. (a)
- Schwartz, B. Two types of pigeon key pecking: Suppression of long- but not short-duration key pecks by duration-dependent shock. *Journal of the Experimental Analysis of Behavior*, 1977, 27, 393-398. (b)
- Schwartz, B., & Williams, D. R. Two different kinds of key peck in the pigeon: Some properties of responses maintained by negative and positive response-reinforcer contingencies. *Journal of the Experimental Analysis of Behavior*, 1972, 18, 201-216.
- Shimp, C. P. Perspectives on the behavioral unit: Choice behavior in animals. In W. K. Estes (Ed.), *Handbook of learning and cognitive processes* (Vol. 2). Hillsdale, N.J.: Lawrence Erlbaum Associates, 1975.
- Shimp, C. P. Short-term memory in the pigeon: Relative recency. *Journal of the Experimental Analysis of Behavior*, 1976, 25, 55-61. (a)
- Shimp, C. P. Organization in memory and behavior. *Journal of the Experimental Analysis of Behavior*, 1976, 26, 113-130. (b)
- Shimp, C. P. Short-term memory in the pigeon: The previously reinforced response. *Journal of the Experimental Analysis of Behavior*, 1976, 26, 487-493. (c)
- Skinner, B. F. The generic nature of the concepts stimulus and response. *Journal of General Psychology*, 1935, 12, 40-65.
- Skinner, B. F. *Behavior of organisms: An experimental analysis*. New York: Appleton-Century, 1938.
- Staddon, J. E. R. Temporal control, attention, and memory. *Psychological Review*, 1974, 81, 375-391.
- Straub, R. O., Seidenberg, M. S., Terrace, H. S., & Bever, T. G. Serial learning in the pigeon. *Journal of the Experimental Analysis of Behavior*, 1979, 32, 137-148.
- Tulving, E. Subjective organization in free recall of "unrelated" words. *Psychological Review*, 1962, 69, 344-354.
- Tulving, E. Intratrial and intertrial retention: Notes towards a theory of free recall verbal learning. *Psychological Review*, 1964, 71, 219-237.
- Vogel, R., & Annau, Z. An operant discrimination task allowing variability of reinforced response patterning. *Journal of the Experimental Analysis of Behavior*, 1973, 20, 1-6.
- Warden, C. J., & Lubow, L. Effect of performance without reward on the retention of the maze habit in the white rat. *Journal of Genetic Psychology*, 1942, 60, 321-328.
- Wasserman, E. A. Conditioning of within-trial patterns of key pecking in pigeons. *Journal of the Experimental Analysis of Behavior*, 1977, 28, 213-220.

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